RAYNER

The Most Advantageous Speeds for Water Turbines

Civil Engineering

B. S.

1909

UNIVERSITY
OF
ILL. LIBRARY

UNIVERSITY OF ILLINOIS
LIBRARY

Class 1909 Book R21 Volume

Ja09-20M

THE MOST ADVANTAGEOUS SPEEDS FOR WATER TURBINES

BY

WILLIAM HORACE RAYNER

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED, JUNE, 1909

1909
R21

1909
R21
2Mr10EE

UNIVERSITY OF ILLINOIS

June 1, 1909

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

WILLIAM HORACE RAYNER

ENTITLED THE MOST ADVANTAGEOUS SPEEDS FOR WATER TURBINES

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

Frank B. Saubon
Instructor in Charge

APPROVED: John P. Brooks

HEAD OF DEPARTMENT OF Civil Engineering

144894

THE RARE BOOK & MANUSCRIPT LIBRARY
UIUC

I N D E X

OBJECT---	PAGE	1
DIVISIONS---	"	1
NOMENCLATURE AND DEFINITIONS----	"	1
DISCUSSION OF CONDITIONS---	"	2
DESCRIPTION OF CURVES---	"	3
COMPARISONS WITH CATALOG RATINGS---	"	15
CONCLUSION---	"	16
DESCRIPTION OF SPEED DIAGRAMS---	"	17

Digitized by the Internet Archive
in 2013

http://archive.org/details/mostadvantageous00rayn

THE MOST ADVANTAGEOUS SPEEDS FOR WATER TURBINES

OBJECT

This thesis has for its object the investigation of the speed of standard American low-head water turbines with a view to arriving at conclusions as regards the most advantageous speed at which a given turbine should run.

DIVISIONS

The thesis will be divided into four general divisions: 1. A general discussion of the conditions which influence the proper speed for a turbine; 2. A description of curves showing graphically the most advantageous speed for a number of standard American turbines; 3. Comparisons with catalog ratings of manufacturers; and 4. Conclusions.

GENERAL DISCUSSION

Nomenclature and definitions:

h = head of water in feet

R.P.M.= revolutions per minute

g = acceleration due to gravity
= 32.2feet per sec. per sec.

R_v = relative velocity

V = theoretical velocity

Peripheal speed is the velocity of the circumference of the turbine, and is usually expressed in feet per second, and may easily be determined when the diameter and revolu-

tions per minute are known.

Theoretical speed is that speed which would be obtained by water falling the net distance h, --it is expressed algebraically by $V = \sqrt{2gh}$

Relative velocity is the ratio of the peripheal speed to the theoretical speed and is expressed by $R_v = \frac{\text{Peripheal Speed}}{\sqrt{2gh}}$

Discussion: There are several conditions which govern the most advantageous speed for a given turbine. Two of these conditions are variations in head of water supply and variations in the demand for power. If the head of water varies from season to season then we have different theoretical velocities developed, and if the turbine is kept at a constant speed as is most likely to be desirable, then a different ratio for the relative velocity will result, causing a change in the efficiency of the turbine. Then if the turbine has been designed to run at maximum efficiency for a given head, when this head is changed the efficiency of the turbine is reduced, and hence it is desirable to choose a relative velocity for the turbine which shall give the greatest efficiency under all conditions due to a change in head. Again, if the demand for power fluctuates to any extent, it is desirable to select a turbine which shall give a maximum efficiency under the most common conditions, and at the same time one which shall not fall much below maximum efficiency under wide conditions of gate opening. Hence at a given plant these two conditions, namely, variable head of water and variable demand for power, should largely determine the kind of

turbine to be selected and the speed at which it is to be run.

DESCRIPTION OF CURVES

The suitability of certain turbines for the two preceding conditions, as determined by actual tests, is shown by the accompanying curves. Each sheet pertains to a single turbine and shows the efficiencies in percent of the different gate openings for different values of relative velocity. For each curve is given a table which is designed to aid in the selection of the best relative velocity for each turbine. The table gives in the columns under the various gate openings, the percentage below the maximum for each particular relative velocity given in the first column. Under the column headed "total" is given the sums of the percentages below the maximum for all the gate openings corresponding to the given relative velocity opposite. Now it is seen that if a given relative velocity is selected and if it is assumed that each gate opening will operate over an equal amount of time during the year then the column of totals will indicate directly the relative velocity giving the least deficiency below the maximum, and hence the most advantageous speed for the turbine. In using these tables, however, it will be assumed that the full gate and the half-gate will each operate over a period of two months, and the three-quarters or seven-eights--gates will operate during the remaining eight months, and the proper weights will be given to the various quantities.

Some high speed turbines are not designed to operate under full gate as is plainly shown by the curves, and in these cases the full gate opening has not been considered. It is also true that the matter of efficiency is not so important when plenty of water is available.

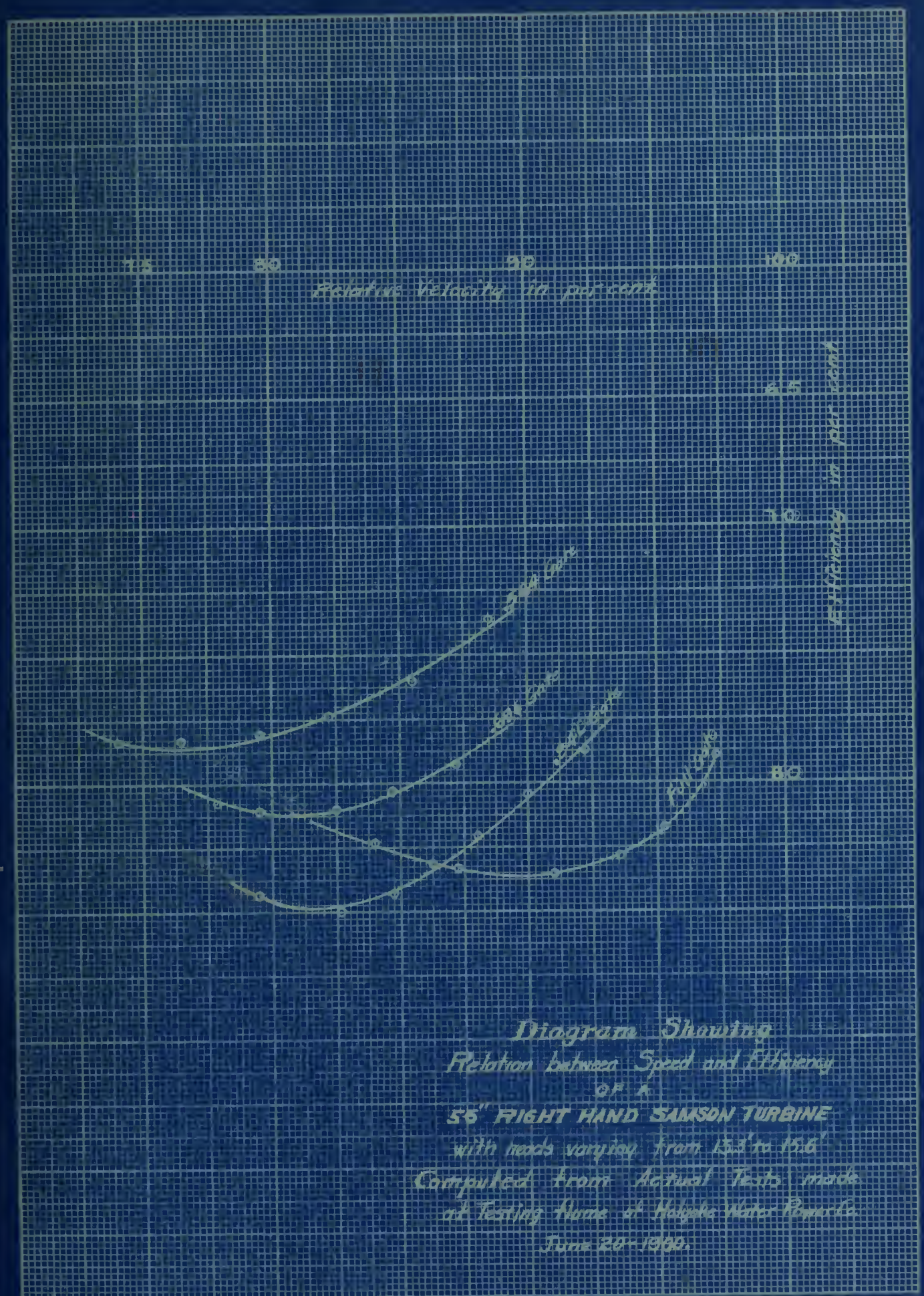
The curves to be discussed have been arranged in two classes that apply to high-speed and low-speed turbines.

56" R. H. Samson Turbine

Relative Velocity in Per Cent	Gate Opening in Per Cent of Full Gate.			Total.
	.564	.696	.846	
77.5	.0	.7	1.5	2.2
80.0	.5	.0	.2	.7
82.5	1.5	.1	.1	1.7
85.0	2.5	1.0	.8	4.3

The full gate opening will not be considered. It is evident from this table that this turbine is best suited to a relative velocity of 80 %. However, there is an advantage gained for the half gate with 77.5 % fpr a relative velocity, and for the .8 gate with a relative velocity of 82.5 %. But since these advantages are nearly equal, the one tending to raise and the other tending to lower the value of the relative velocity to be selected, it will be seen that for all conditions 80 % would be the best value.

This relative velocity for 16' head corresponds to a peripheal speed of 25.6 feet per second, or 105 R. P. M.



EUGENE DIETZGEN CO., CHICAGO.

45" Right Hand Samson Turbine

Relative Velocity in Per Cent	Gate Opening in Per Cent of Full Gate.				Total.
	.57	.68	.83	1.00	
80.0	.0	.0	1.2	2.0	3.2
82.5	.5	.5	.5	1.2	2.7
85.0	1.5	1.5	.1	.7	3.8
90.0	3.7	4.5	.2	.0	8.4

The test data for this wheel is very complete, and the curves indicate large variations in relative velocity. The full gate curve may be considered in this case since it is compared with the other curves. It appears that a relative velocity of 82.5 % gives the most advantageous speed for all conditions. From the column of totals it is seen that the deficiency below the maximum is 3.2 % for R_v = 80 %, and is 3.8 % for R_v = 85 %. Hence 82.5 % is the value of R_v to be chosen for all possible conditions.

This relative velocity for 15' head corresponds to a peripheal speed of 26.4 feet per second, or 134 R. P. M.

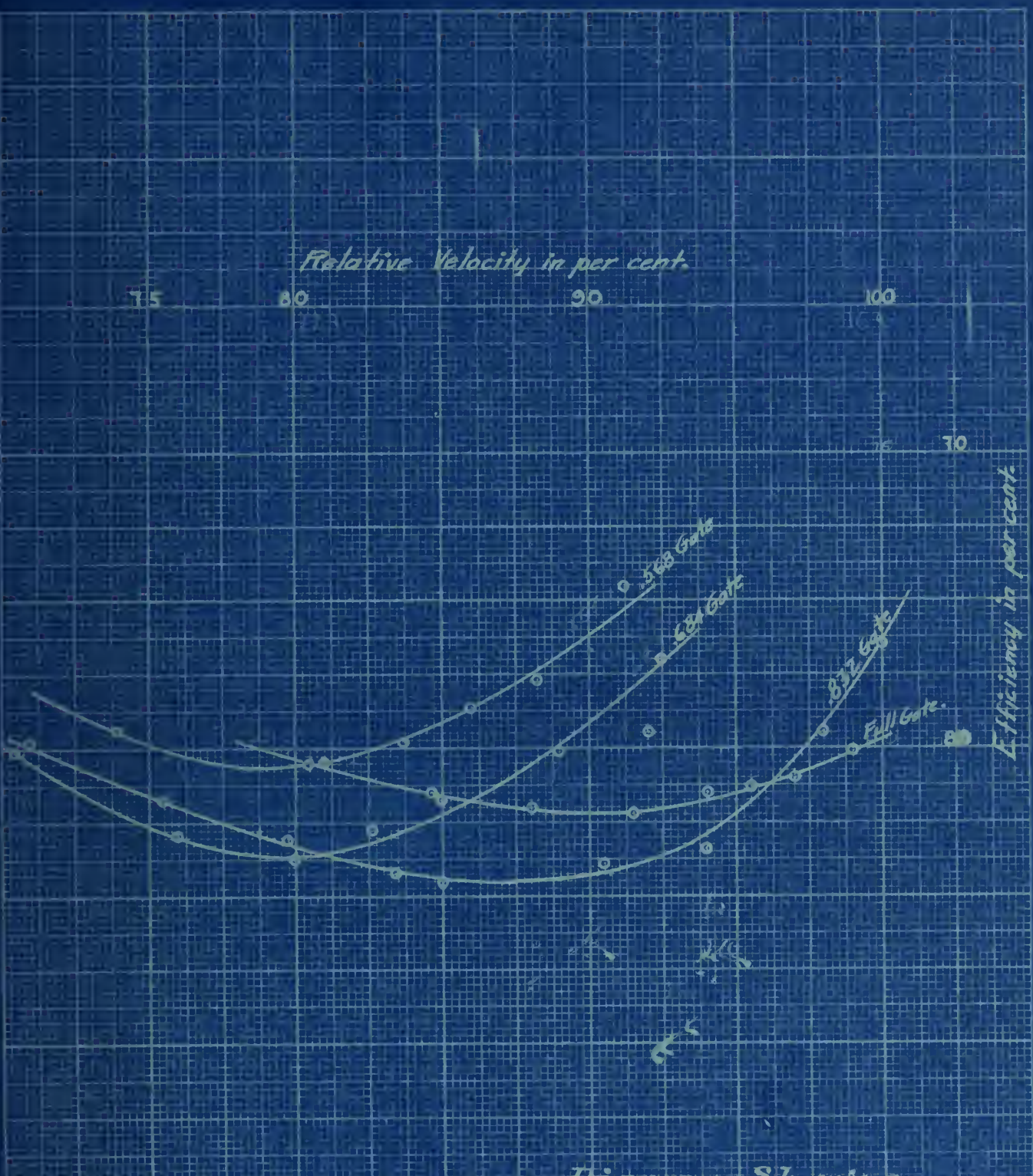


Diagram Showing

Relation between Speed and Efficiency

OF A

45" RIGHT HAND SAMSON TURBINE

with heads varying from 14.0' to 16.5'

Computed from Actual Tests made at

Testing Flume of Holyoke Water Power Co.

Jan. 26-1897.

44" L. H. Imp. New AM. Turbine

Relative Velocity in Per Cent.	Gate Opening in Per Cent of Full Gate.			Total.
	.581	.684	.823	
72.5	.0	.2	3.1	3.3
75.0	.7	.0	2.0	2.7
77.5	1.5	.5	1.2	3.2
80.0	2.7	1.5	.5	4.7

The curves for this turbine indicate that the full gate opening should not be considered in selecting a value of R_v for the other gates.

The table shows 75 % as the value of R_v most favorable to all conditions. The column of totals shows that should 72.5 % be chosen, the total loss of efficiency from the other gate openings would be 3.3 %, and should 77.5 % be used, the total loss would be 3.2 %. Since these two losses are very nearly equal in value it is seen that no change should be made in the selection of a relative velocity of 75 % as best suited to the varying conditions.

This value of R_v corresponds to a peripheal speed of 24.0 feet per second, or 125 R. P. M.

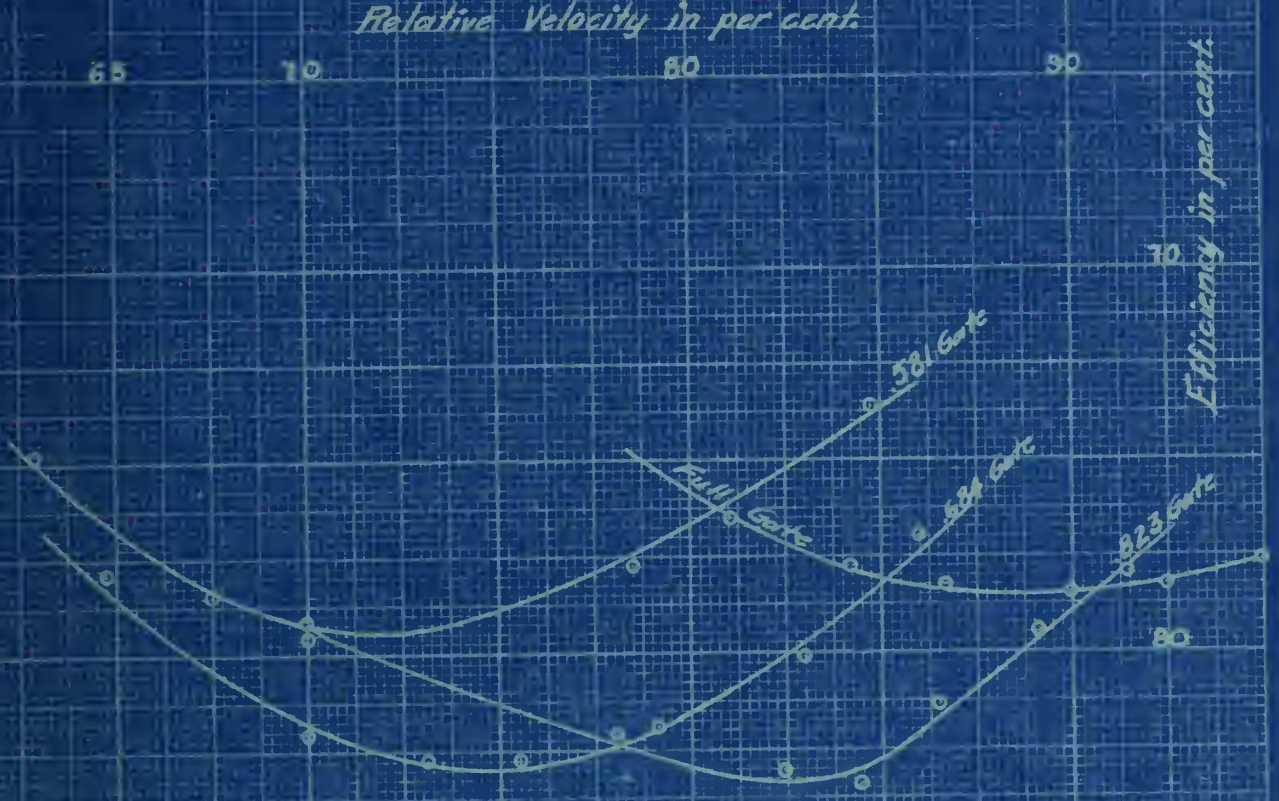


Diagram Showing
Relation between Speed and Efficiency
OF A
44" L.H. IMPROVED NEW AMERICAN TURBINE
with heads varying from 15.2 to 17.0'
Computed from actual Tests made
at Testing flume of Holyoke Water Power Co.
March 21-1904.

57" Left Hand McCormick Turbine.

Relative Velocity in Per Cent.	Gate Opening in Per Cent of Full Gate.				Total.
	.483	.650	.770	1.00	
65.0	.2	.1	1.5	.8	3.2
70.0	.5	.2	.5	.0	1.2
75.0	2.5	2.0	0	.0	4.5

This curve indicates that this turbine is well adapted to full gate operation since the efficiency is near a maximum over a large range of relative velocity. From the first inspection of the curve, 70 % would be chosen for the best value of R_v for all conditions. However, it is seen that for R_v = 65 %, the deficiency for the two lower gates below the maximum is 3.3 % and for 75 % the total is 4.5 %. Hence if for part of the year the turbine should be run at the low gates and part of the year at the higher gates then a change should be made in favor of the lower gates. Giving the proper weights to the different gate openings it is found that 693 % is the best value of R_v for the different conditions throughout the year.

This value of the relative velocity corresponds to a peripheal speed of 23.5 feet per second or 89 R. P. M.

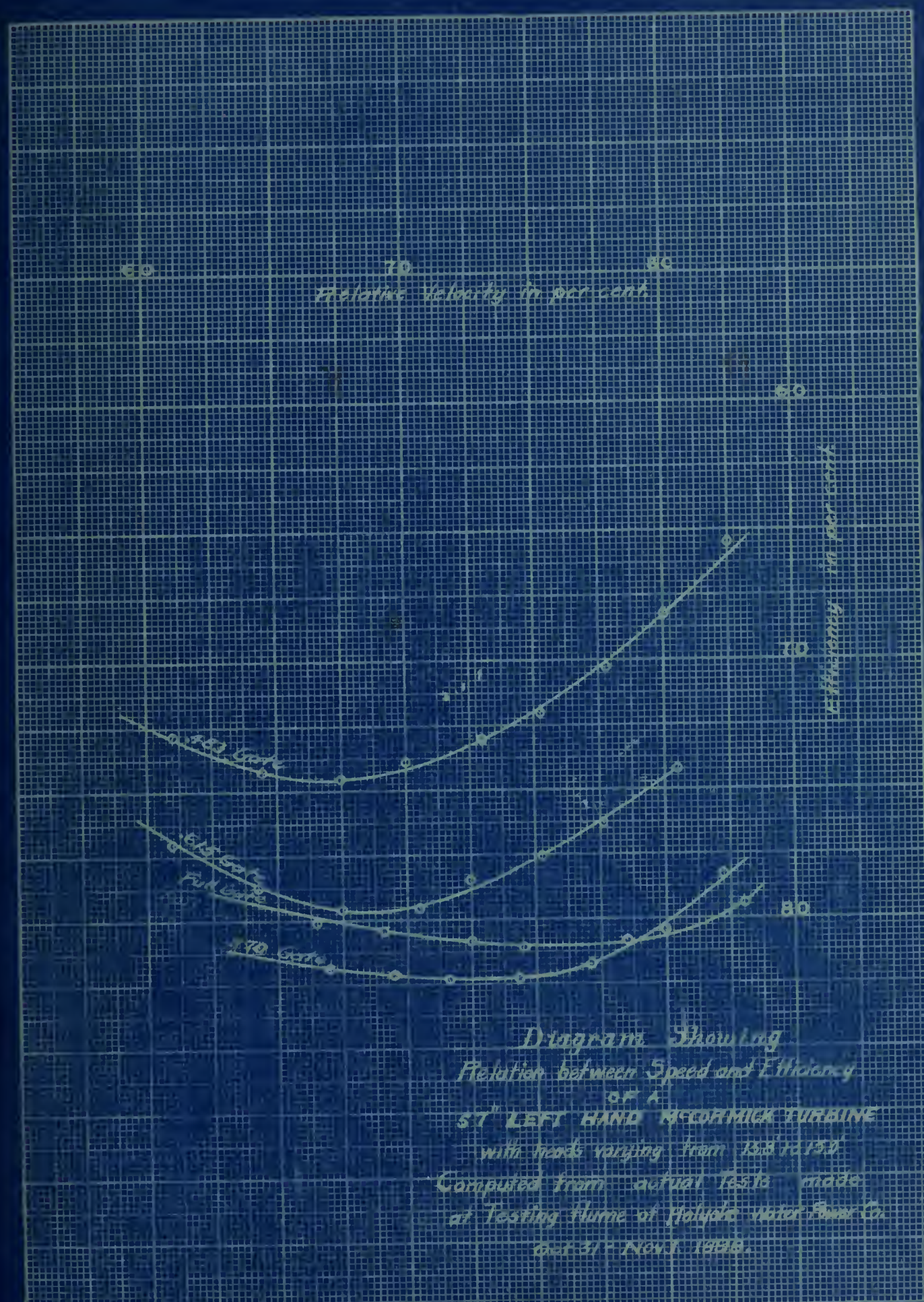


Diagram Showing
Relation between Speed and Efficiency
of a
57" LEFT HAND McCORMICK TURBINE
with heads varying from 18.8 to 15.2'
Computed from actual Tests made
at Testing Flume of Holyoke Water Power Co.
during NOVEMBER 1888.

EUGENE DIETZGEN CO., CHICAGO.

42" Smith Turbine

This curve is interesting as an example of the inaccuracy and inadequacy of a single-gate test as a basis for the selection of the best relative velocity for a turbine. This curve was constructed from data sent out by the Morgan Smith Co. as an authoritative rating for their turbine.

The curve corresponds closely with the full gate curves of other high-speed turbines, and without doubt the lower gate openings would give a much lower relative velocity for maximum efficiency. Judging from the relative velocity selected for the other high speed turbines, it would not be much in error to give 80 % as the best relative velocity for this turbine under all conditions.

This is seen to be 10 % lower than the value indicated by this one curve, and would reduce the speed from 157 to 140 R. P. M.

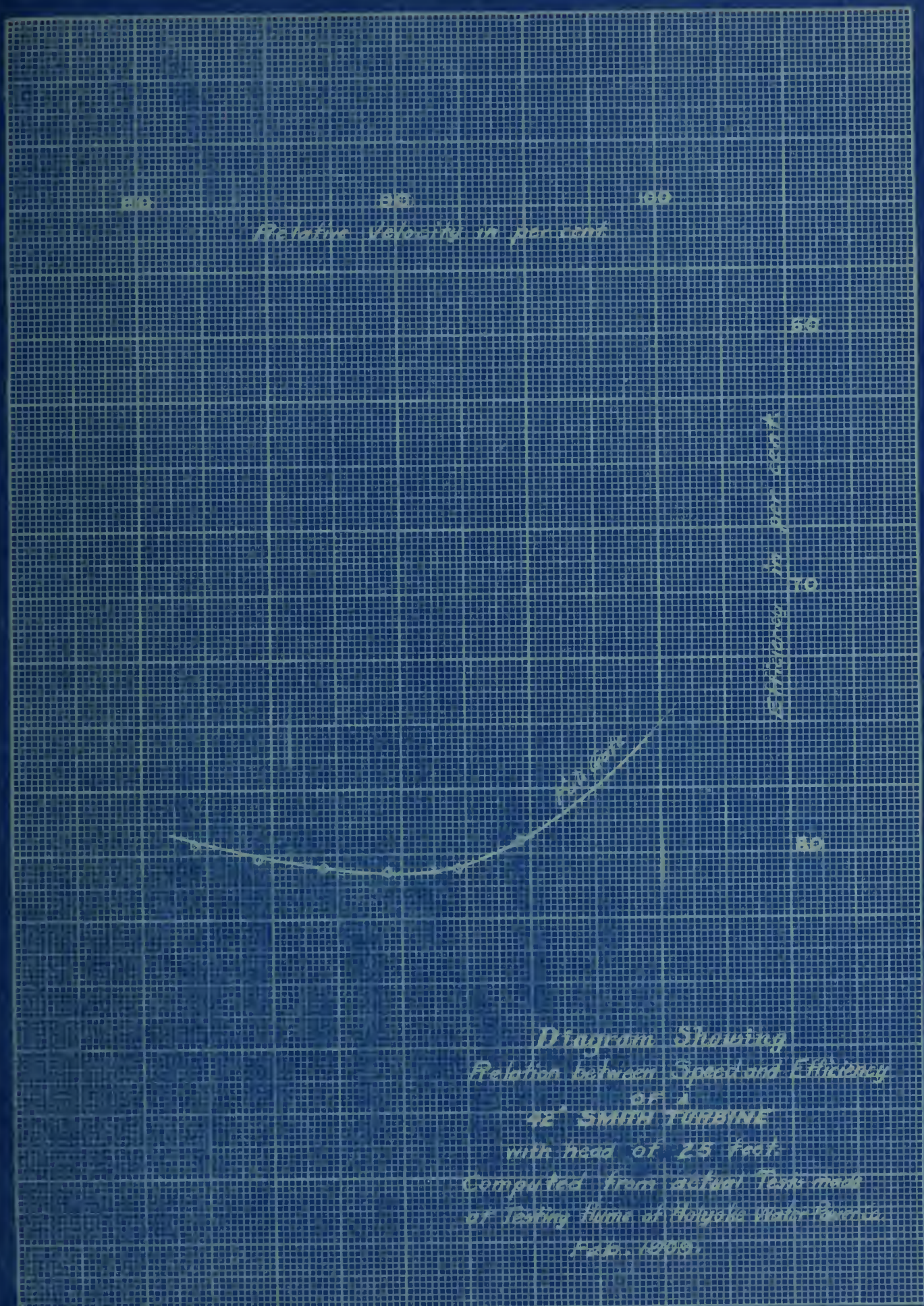


Diagram Showing
Relation between Speed and Efficiency
of a
42" SMITH TURBINE
with head of 25 feet
Computed from actual Test made
at Testing flume at Holyoke Water Power
Feb., 1905.

EUGENE DIETZGEN CO., CHICAGO.

54" R. H. Special

The curves for this turbine indicate that it has been designed for high-gate openings since for the 7/8 and full gate the range of relative velocity is very wide, in which a high efficiency may be obtained. The lower gates give sharper curves but may well be used at a relative velocity favorable to the higher gate openings.

Relative Velocity in Per Cent	Gate Opening in Per Cent of Full Gate.				Total.
	.50	.67	.87	1.00	
65.0	.0	.7	.0	.0	.7
67.5	.2	.0	.0	.0	.2
70.0	1.0	.0	.2	.2	1.4
72.5	2.5	1.0	.7	.7	4.9

From these figures there is but one velocity to choose, namely, 67.5 %. This gives but .2 % total deficiency for all gates. Hence for all conditions this velocity would give maximum efficiency.

This relative velocity corresponds to a peripheal speed of 21.6 feet per second, or for a 54" turbine equals 91.7 R. P. M.

Diagram Showing
Relation between Speed and Efficiency
of A
54" R.H. SPECIAL HERCULES TURBINE
with heads varying from 149 to 162
Computed from Actual Tests made at
Testing Flume of Holyoke Water Power Co.
Nov. 12-1897.

51" L. H. McCormick

This turbine under variable conditions is not well adapted to full gate operation since for this gate the speed is far below a maximum for the other gates of the turbine. However, the highest efficiency of the turbine is gained under full gate operation, and for steady conditions and plenty of water it could most advantageously use the full gate opening.

Relative Velocity in Per Cent	Gate Opening in Per Cent of Full Gate.				Total.
	.50	.67	.87	1.00	
67.5	.0	.2	.7	1.5	2.4
70.0	.2	.0	.1	1.0	.4
72.5	1.0	.5	.0	.5	2.0
75.0	2.2	1.7	.7	.0	4.6

The losses in efficiency here indicate a relative velocity of 70 % as most suitable to all conditions. If the lower gates were to receive lesser weights, i.e., where plenty of water is usually available, then the relative velocity would be increased to gain the efficiency of the higher gate openings.

This speed of 70 % relative velocity at 16 feet head corresponds to a relative velocity of 22.4 % or a speed of 100.1 R. P. M.

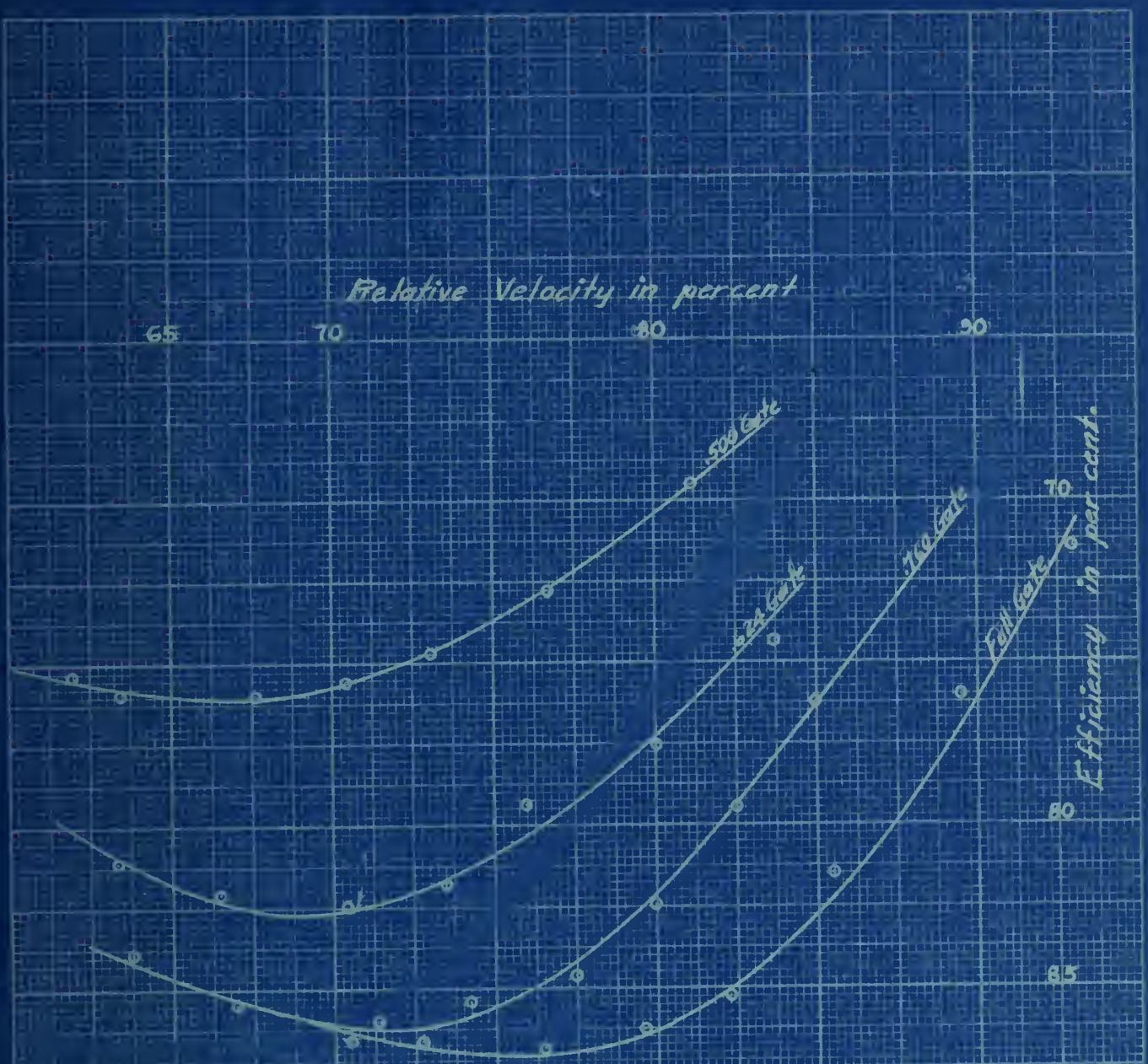


Diagram Showing
Relation between Speed and Efficiency
of a
51" L.H. McCORMICK TURBINE
with heads varying from 14.7 to 16'
Computed from Actual Tests made at
Testing Flume of Holyoke Water Power Co.
Feb. 20-1903.

36" Right Hand Swain Turbine

Relative Velocity in Per Cent	Gate Opening in Per Cent of Full Gate.				Total.
	.50	.75	.87	1.00	
67.5	0.0	.7	.2	.0	.9
70.0	0.0	.2	.0	.2	.4
72.5	.3	.0	.0	1.0	1.3

This turbine is excellently adapted to varying conditions in head and gate since the efficiency is near a maximum over a wide range in relative velocity.

This table shows 70 % to be the most advantageous velocity to use under all conditions. However, it is seen that the maximum for the average gates 3/4 and 7/8 comes when the relative velocity is 72.5 % and that for half and full gate 67.5 is a better speed. Since these are opposing conditions it is plain that 70 % should be slected for operation under the varying conditions.

This corresponds to a relative velocity of 33.4 % or a speed of 142 R. P. M.

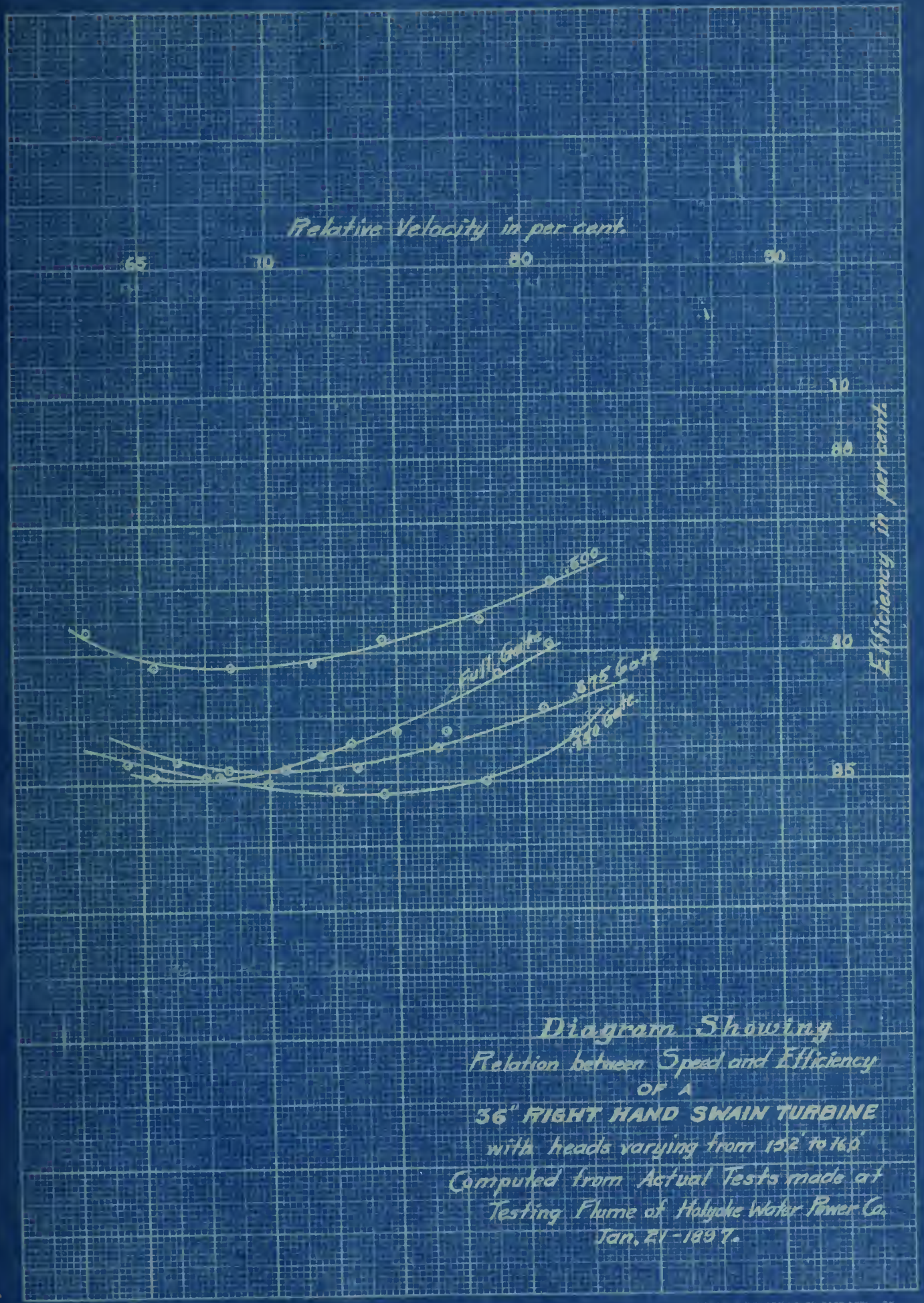


Diagram Showing
Relation between Speed and Efficiency
OF A
36" RIGHT HAND SWAIN TURBINE
with heads varying from 15.2' to 16.0'
Computed from Actual Tests made at
Testing Flume of Holyoke Water Power Co.
Jan. 21 - 1897.

33" Special Turbine

Relative Velocity in Per Cent	Gate Opening in Per Cent of Full Gate.			Total.
	.50	.75	.87	
70.	1.0	.2	3.8	5.0
75.	2.0	.7	2.0	4.7
80.	3.0	3.0	.5	6.5

This turbine has a very unusual set of curves making it very difficult if not impossible to select any one speed which shall give the best results under varying conditions. The curves are widely separated giving widely different relative velocities for a maximum under different gate openings, and moreover each curve has a narrow range within which a maximum efficiency may be approximated. Full gate is not considered.

The table seems to show some preference to a relative velocity of 75 %, and since the difference between the 70 % and 80 % velocity is very small there would be no practical advantage in favor of either.

The turbine was evidently not designed to include full gate opening. A relative velocity of 70 % at 16 ft. head corresponds to a peripheal speed of 33.4 feet per second or 155 R. P. M.

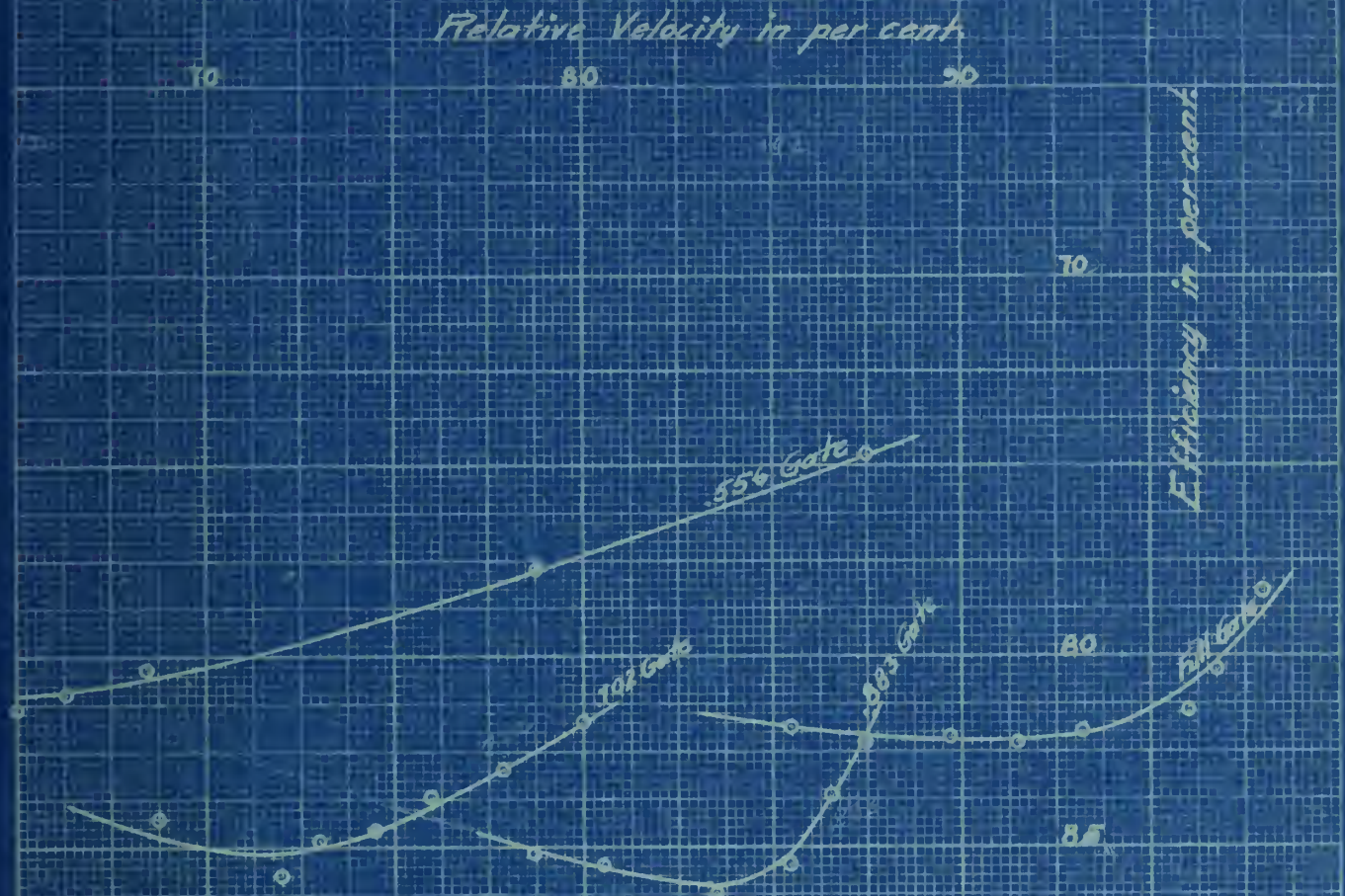


Diagram Showing
Relation between Speed and Efficiency
of A
33" SPECIAL TURBINE
with heads varying from 11.0' to 11.8'
Computed from Actual Tests made at
Testing Flume at Holyoke Water Power Co.
March 26-1904.

16" Right Hand New American Turbine

Relative Velocity in Per Cent	Gate Opening in Per Cent of Full Gate.				Total
	.50	.75	.87	1.00	
67.5	.1	.2	.5	.1	2.1
71.0	.0	0	0	.2	.2
75.0	.1	.1	.2	.5	2.1

This turbine has a comparatively wide range of relative velocity for each gate opening over which nearly a maximum efficiency may be obtained. Moreover, the value of the proper relative velocity for one gate opening is very nearly the same for all, making this turbine a very excellent one for variable conditions.

The table shows that within a range of 7.5 % relative velocity there is no one gate opening that varies as much as 1 % from the maximum. 71 % is seen to be best adapted to varying conditions and hence this speed should be used for this turbine.

A relative velocity of 71 % at 16 ft. head corresponds to a peripheal speed of 22.7 feet per second or 334 R. P. M.

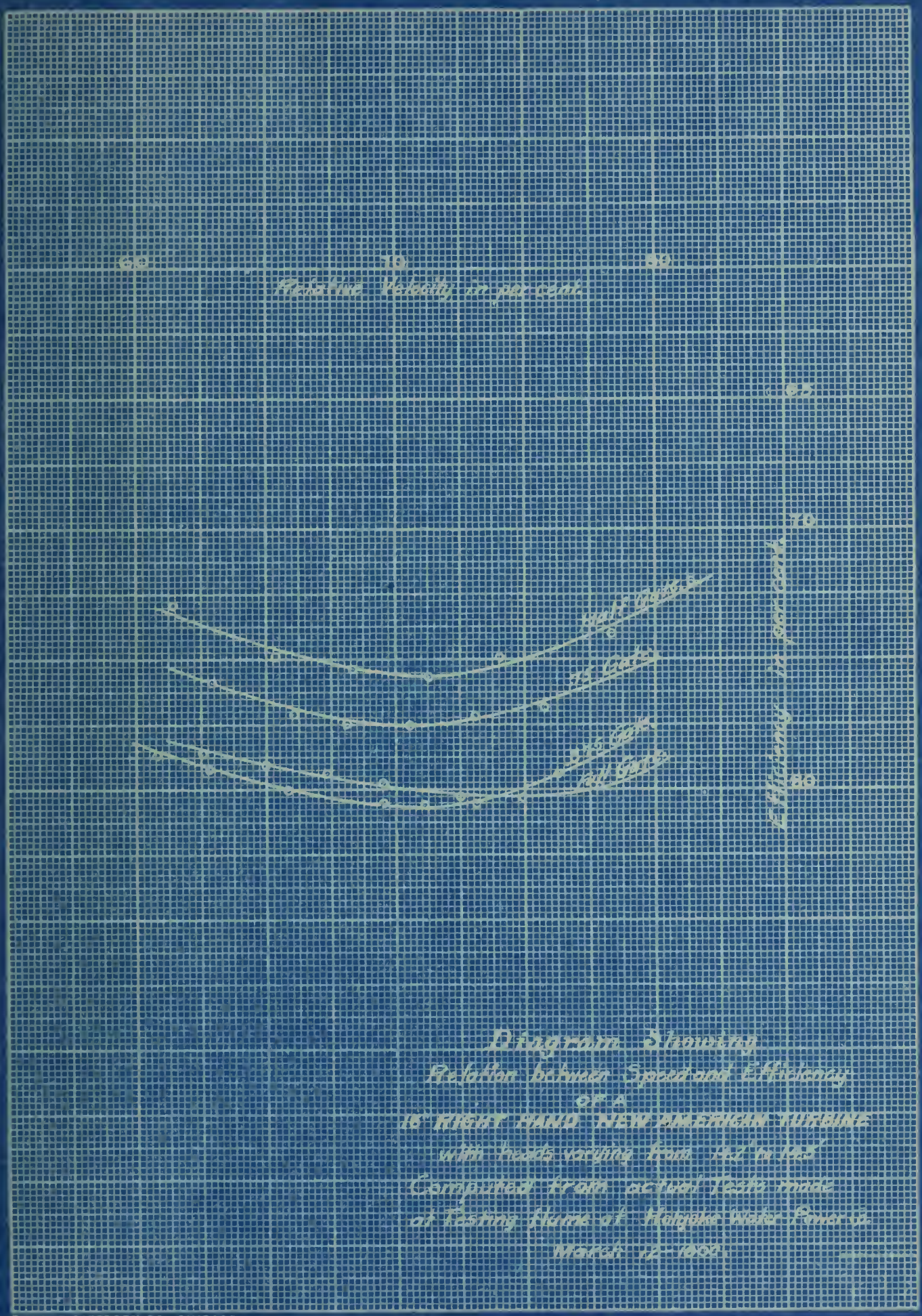


Diagram Showing
Relation between Speed and Efficiency
of a
16" RIGHT HAND TURBINE
with heads varying from 16.2 to 26.2
Computed from actual tests made
on Testing Flume of Holyoke Water Power Co.
March 12, 1902

EUGENE DIETZGEN CO., CHICAGO.

COMPARISONS

It will be of interest to compare the speeds determined upon by this thesis with some of those given in the catalogs of the manufacturers. Thus for the Samson turbines described above, the speeds decided upon for 16 ft. heads were 105 R. P. M. for the 56" turbine and 134 R. P. M. for the 45" turbine. For the same turbine and heads of water the manufacturers give 116 R. P. M. for the 56" turbine and 145 R. P. M. for the 45" turbine. This is a difference of 11 R. P. M. in each case and would show that the manufacturers have either given more weight to full gate openings or have used these speeds in competition with other makers as making a better showing for the turbine.

A test made in the Hydraulic Laboratory of the University of Illinois gave as the speed for maximum efficiency of a 12" Leffel turbine under 16 ft. head a value of 480 R. P. M. From the curves here investigated of turbines of the same make, a relative velocity of 80 % was selected and this corresponds to a speed of 490 R. P. M. under similar conditions. This is a close check on the accuracy of the value of relative velocity selected above. In general it may be assumed that the ratings in makers' catalogs will be a little high, and it is much more desirable to make the selection of the proper speed from the actual test data for the different gate openings.

CONCLUSION---

Classification of Turbines

NAME	DIAMETER IN INCHES	BEST RELATIVE VELOCITY	R.P.M. UNDER 16 FT. HEAD	
(R.H.)Samson	56	80.0	105	High Speed
(R.H.)Samson	45	82.5	134	
(L.H.)Imp.New Am.	44	75.0	125	
Smith	42	80.0	142	
(L.H.)McCormick	57	69.3	89	Low Speed.
(R.H.)Special	54	67.5	92	
(L.H.)McCormick	51	70.0	100	
(R.H.)Swain	36	70.0	142	
Special	33	70.0	155	
(R.H.)New Am.	16	71.0	324	

In conclusion a classification of the turbines in regard to their relative speeds will be helpful in drawing conclusions as to what is the most advantageous speed for water turbines.

From an inspection of the curves according to the above classification a number of important facts are evident. First, the curves for high speed turbines show in each case that the full gate test should not be used as the basis upon which to select the most advantageous speed for the turbine. This fact is plain since the full-gate curves are quite separate from the other curves and cut across the latter at sharp angles. The high speed curves indicate, moreover, a narrow range in relative velocity within which a maximum efficiency may be secured. These facts clearly indicate

that high speed turbines serve better for stable conditions of head and water supply than where the conditions vary.

The curves for the low speed turbines show in each case that the operation may well include the full gate opening and this opening should be considered in deciding upon the proper speed for each turbine. The low speed curves are remarkably parallel and are comparatively flat, giving wide ranges of relative velocity within which to select the best speed. These facts make the low speed turbines excellently adapted to conditions which demand variations in head and gate openings, and the low speed would seem to be superior to the high speed turbine under these conditions.

Finally, it may be stated that the most advantageous speed can only be determined upon when complete test data is available from which a relative velocity may be chosen which shall be best suited to all conditions to be imposed upon the turbine.

The two diagrams appended have been prepared especially for this thesis and are valuable in finding the revolutions per minute, the diameter of turbine, a head of water when any two of the variables are known. A straight line between any two known quantities will intersect the third line at a point giving an exact relation between the three quantities.

For example a certain turbine, 45" diameter, is to operate under 14 ft. head with a relative velocity of 75 %, and it is desired to know the revolutions per minute at

which to run the turbine. Selecting the diagram with a relative velocity of 75% and laying a straight edge from 14 ft. on the right hand curve to 45" on the left hand curve the value of 114 R.P.M. is found as the correct speed.

Again, the head of water may be known to be 16 ft. and the turbine is to run at 150 R.P.M. with 70% relative velocity. It is desired to find the proper size of turbine. By the use of a straight edge upon the known quantities the third line is intersected at a point reading 34" which is the correct diamter of turbine to be used.

Should it be desirable to use any value of relative velocity other than those given on the curves, the correct answers may be obtained by the use of a direct ratio between the relative velocity desired and that given by the curves.

DIAGRAM FOR SPEED OF WATER TURBINES

$$\text{RELATIVE VELOCITY} = \frac{\text{PERIPHEAL SPEED}}{\sqrt{2GH}}$$

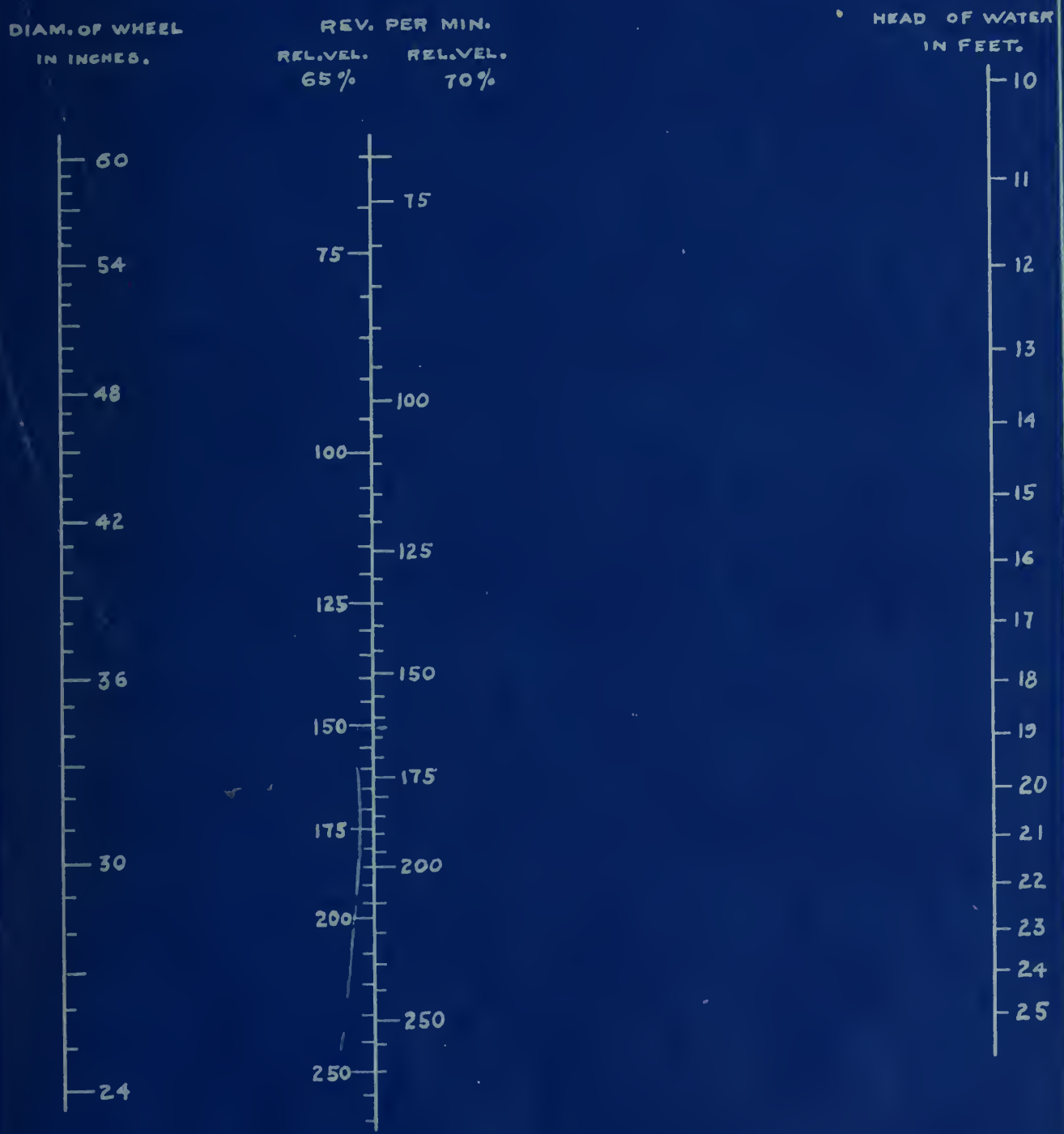
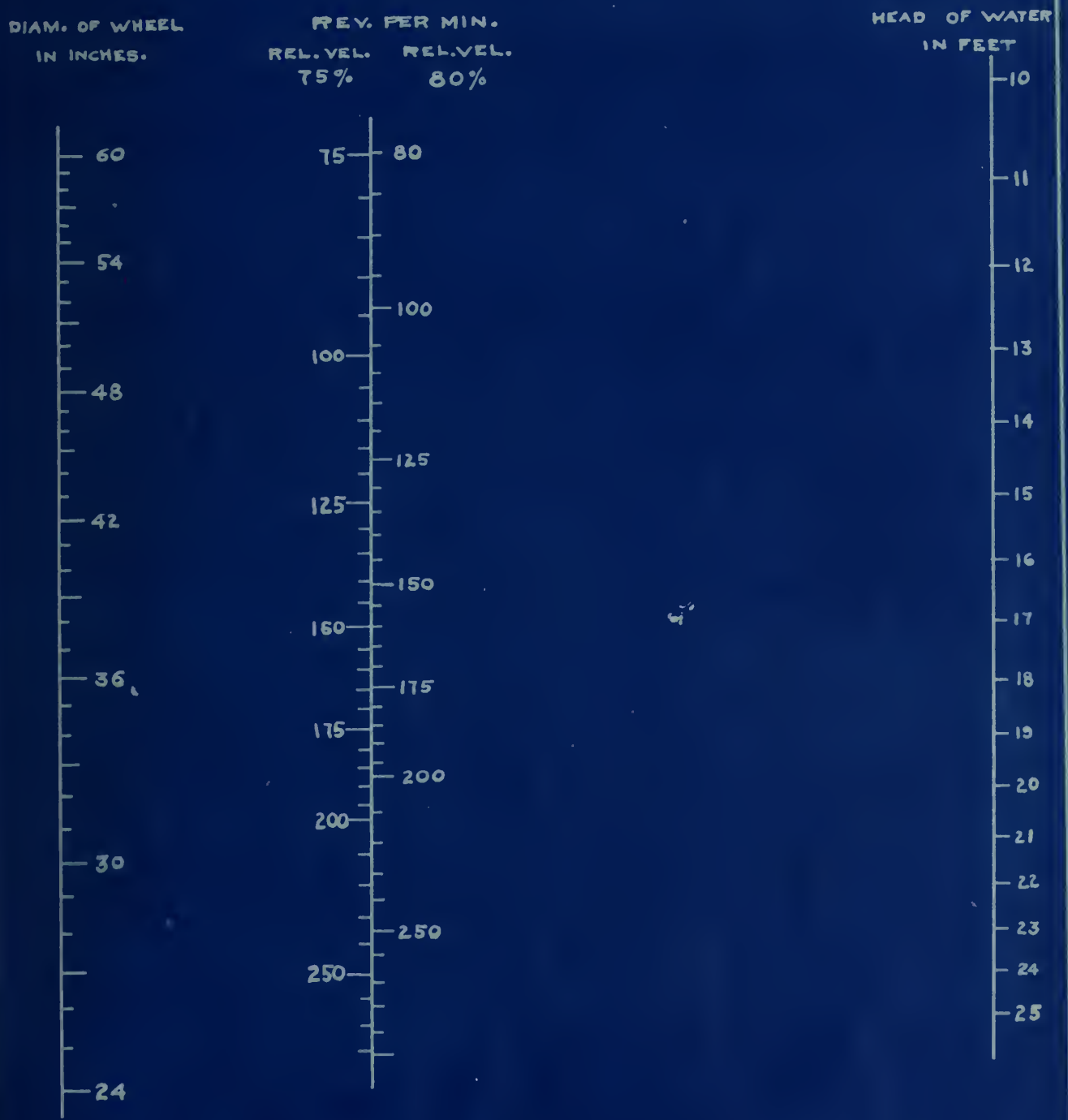


DIAGRAM FOR SPEED OF WATER TURBINES.

$$\text{RELATIVE VELOCITY} = \frac{\text{PERIPHEAL SPEED}}{\sqrt{2GH}}$$



UNIVERSITY OF ILLINOIS-URBANA
3 0112 079093982